Range Commanders Council

DOCUMENT 801-98
(Revised March 1999)

SIGNATURE MEASUREMENT STANDARDS GROUP
RADAR CROSS SECTION COMMITTEE

RADAR CROSS SECTION (RCS)
MEASUREMENT FACILITY CATALOG

WHITE SANDS MISSILE RANGE
KWAJALEIN MISSILE RANGE
YUMA PROVING GROUND
DUGWAY PROVING GROUND
ABERDEEN TEST CENTER
NATIONAL TRAINING CENTER

ATLANTIC FLEET WEAPONS TRAINING FACILITY
NAVAL AIR WARFARE CENTER WEAPONS DIVISION
NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
NAVAL UNDERSEA WARFARE CENTER DIVISION, NEWPORT
PACIFIC MISSILE RANGE FACILITY
NAVAL UNDERSEA WARFARE CENTER DIVISION, KEYPORT

30th SPACE WING
45th SPACE WING
AIR FORCE FLIGHT TEST CENTER
AIR ARMAMENT CENTER
AIR WARFARE CENTER
ARNOLD ENGINEERING DEVELOPMENT CENTER
GOLDWATER RANGE
UTAH TEXT AND TRAINING RANGE

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RADAR CROSS SECTION MEASUREMENTS FACILITY CATALOG

DECEMBER 1998

Prepared by

Signature Measurement Standards Group
Radar Cross Section Committee

Published by

Secretariat
Range Commanders Council
U.S. Army White Sands Missile Range,
New Mexico 88002-5110

Preface

As a lead in to this document, a short history of its genesis and the organization behind it is in order. The radar Cross Section Measurements Working Group (RCSMWG) was originally formed to respond to tasking generated by the Department of Defense Tri-Service Electronic Combat Reliance Panel 2. Specifically, the RCSMWG was comprised of representatives from all government-owned facilities related to radar cross section (RCS) measurements. The original product of the RCSMWG was the Test Capability Master Plan (TCMP), which was prepared as an adjunct to the 1992 EC TCMP for the EC Reliance Panel 2.

Though the EC Reliance tasking was completed with the delivery of the TCMP, the group found that continued tri-service cooperation was beneficial to all involved, particularly with respect to common technical issues. The RCSMWG embarked on three separate—but jointly funded projects—including (1) a review by the National Institute of Standards and Technology (NIST) of all DoD RCS range error budgets (uncertainty analysis), (2) the development of a common, exchangeable data format for data generated by any DoD range, and (3) the establishment of this facilities catalog. The catalog was to contain DoD range information and be a service to DoD program managers requiring information on available RCS measurement capabilities.

The original members of the RCSMWG who participated in the production of this document were:

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Keith Gruhot	RCSMWG Vice-Chair, NAWCWD (China Lake, CA)
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The Range Commanders Council (RCC) seeks to preserve and enhance the nation's warfighting superiority by ensuring that affordable technical capability and capacity are available to test and operate the world's most effective weapons systems and to train the warfighters who use them. The RCC is dedicated to serving the technical and operational needs of the DOD test, training, and operational ranges. It is made up of numerous units throughout the Armed Services. The scope of activity of the RCC is: to resolve common problems; discuss common range matters in an organized forum; exchange information and thereby minimize duplication; conduct joint investigations pertaining to research, design, development, procurements, testing, and interoperability; coordinate major or special procurement actions; develop operational procedures and standards for present and future range use; and encourage the interchange of excess technical systems and equipment. As such, the RCC appeared to be a viable structure into which to assimilate the RCSMWG. In 1994, the Signature Measurements Standards Group (SMSG) was formed under the RCC, and the Radar Committee was formed as one of three initial standing committees to pursue issues related to radar, radar cross section measurements and millimeter-wave technologies.

The purpose of this catalog is to provide basic information about the resources available and to provide points of contact for program managers in need of such capabilities to support research, development, test and evaluation. These facilities can carry out the full range of activities required in the RCS measurement process, including test planning, test item preparation, collection of actual measurement data, processing, analysis and post-test assessments. This document represents the third edition and includes information about the major DoD and NASA facilities that produce and, in some cases, are repositories of RCS data.

For general information about RCS measurements, you may contact the following:

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Introduction

This document lists the major radar cross section (RCS) measurement facilities owned and operated by the US Government, and gives points of contact for interested parties in need of additional information concerning RCS measurements. This document was assembled by the Radar Committee of the Signature Measurements Standards Group (SMSG) of the Range Commanders Council (RCC), formerly the Radar Cross Section Measurements Working Group (RCSMWG). Its purpose is to provide program managers, engineers, scientists and others basic information on RCS measurement facilities and to provide points of contact at each facility.

It should be clearly understood that this catalog is not totally inclusive of all government facilities able to carry out RCS measurements. Rather, it lists all the major facilities whose charter is to conduct comprehensive RCS measurements, and have the necessary facilities, full-time staff and other resources to do so. As such, these facilities are listed in the RCS Measurement Facilities (RMF) Test Capabilities Master Plan (TCMP) that was prepared as an adjunct to the Electronic Combat (EC) TCMP for Project Reliance Panel 2 (Electronic Combat). That plan was developed by a Department of Defense Tri-Service working group, and represents their evaluation of existing government RCS measurement facilities.

The facilities listed herein have the indigenous resources to conduct test planning, test item preparation, conduct measurements, collect and process data, reduce data and provide post-test assessments. Similarly, the expertise necessary to guide non-RCS-literate personnel through the processes in an understandable fashion is available at each facility. For the sake of enhancing the utility of this document, a few other facilities that carry out functions related to RCS, like RCS data warehousing and distribution, are included.

This document is arranged to provide a brief introduction, some technical background, a map showing the geographic location of each facility included, and a service-by-service grouping of the various facilities. Each description contains one or two photographs along with basic parameters. As this document is releasable to the public, no mention of classified parameters nor capabilities is included. Several appendices are provided to assist readers in understanding the acronyms and terminology used in the RCS community.

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Technical Background

This section is meant to give those new to the RCS measurement process the background necessary to appreciate the differences between the many types of government facilities—generally referred to as *ranges*. Though it might appear there is needless duplication between the various ranges, there are sound technical reasons for the numbers and types of facilities owned and operated by the government. Since the early 1990's, several studies have addressed the apparent duplication (and costs associated therewith). Where duplication exists, it is either fully justified or marginally justified. If marginally justified, the facilities involved have been closed outright, mothballed or consolidated.

To understand the subtle differences, the reasons for making RCS measurements are reviewed. Next, the kinds of ranges are briefly discussed. Then, major factors that should be considered when choosing between ranges are presented. Finally, sources of additional information re provided.

Reasons for Making RCS Measurements

RCS measurements are made for many purposes, and the purpose the measurements serve will often determine what type of range should be selected. There are fundamentally two primary reasons to know the RCS of an object: civil and military. Civil airspace management employs radar to monitor the location of aircraft for safety and control. Military uses include detecting enemy aircraft, ships or ground vehicles; knowing where friendly vehicles are; and to predict survivability and vulnerability of vehicles and their associated crews as they are introduced into a field of battle. Among the purposes for conducting measurements are: basic and applied research and development (R&D); design of components, subsystems and systems; verification and validation of prediction codes and other measurements; acceptance testing (specification compliance); and diagnostic measurements in support of logistical requirements such as repair, Pre-Planned Product Improvements (P3I). Not only does the purpose of the measurement help determine what type of facility should be selected; the purpose will usually determine the range of achievable values for the various measurement parameters desired and which facilities can meet those requirements.

Each of the military services has unique reasons for making RCS measurements as dictated by their different missions. Whereas all the services have requirements to measure flying vehicles, the Navy has the requirement to measure air vehicles close to the water, the Air Force has a requirement to measure very large air vehicles, and the Army has a requirement to measure relatively slow moving air vehicles. These examples of what might be considered relatively minor distinctions can have tremendous impact on the nature of the facility design and its location. More intuitive differences include the Army's need to measure ground vehicles, and the Navy's need to measure ships. Because of the apparent, and sometimes the less apparent differences, the services have developed ranges with genuinely unique characteristics. A beneficial by-product is some redundancy in capabilities.

Kinds of RCS Measurement Ranges

Just as there are many reasons to make RCS measurements, there are many types of ranges and configurations of range resources. Each of the government ranges has a different configuration and is capable of making different types of measurements, over differing frequency bands, with various modulations and parameters, and with differing clutter and background levels. Each range has different target[1] handling capabilities based on size and weight. In the paragraphs that follow, we will discuss the types of ranges with respect to near- and far-field, monostatic and bistatic, indoor and outdoor, static and dynamic.

Far-Field versus Compact Ranges

The equation that defines RCS assumes that the radar wave that is incident upon a target arrives in-phase and at the same amplitude in a plan that sweeps across the target. However, when a wave is launched (transmitted from its source), it usually comes from a source that generates waves with a spherical or curved wave front. As the wave moves away from the transmitter, the wave front becomes more planar in a localized region, thus, the key to achieving a planar wave front at the target is to locate the target a sufficiently large distance from the transmitter. This distance is based upon a criteria relating to target size and wavelength (or frequency) of the incident wave, and is known as the far-field criteria. Ranges that meet the far-field criteria by using a large physical separation between the transmitter and target are known as far-field ranges. Because the distance is inversely proportional to the wavelength, smaller wavelengths (or higher frequencies) require longer separation distances. Thus, the far-field criteria can be difficult to meet for large targets at short wavelengths, often requiring large amounts of real estate for the range.

To reduce the real estate requirements, compact ranges have been developed. A compact range is one where the plane wave requirements of the incident wave are met not by distance but by the focusing and collimating[2] effects inherent in certain geometrical configurations. For instance, placing a filament of a headlight at the focal pint of a reflector will result in an increase in the apparent beam strength by collimating all of the light into a narrow beam. In much the same way, we can achieve a focused, collimated beam by placing an antenna at the focal point of an electromagnetic reflector. The advantage of this approach is that we effectively obtain a planar wave in a much smaller distance, greatly reducing the real estate required to make a valid measurement configuration. The downside is that we have only a finite region[3] where our planar wave front is achieved. Also, for long wavelengths (low frequencies), the reflector size can be prohibitively large for large targets.

Monostatic Versus Bistatic Ranges

When we measure the radar return (bounced signal) from a target, we usually obtain the back-scattered radar return as it arrives at the originating point. That is, when the target is illuminated by radar, the target will re-radiate the radar wave, acting much like an antenna. Thus, the incident wave will be scattered in a three-dimensional pattern about the target. Although the pattern that is given off the target will be radiated in many directions, it will be received only if it intercepts a receiving antenna. Since the receiving antenna is normally collocated with the transmitting antenna (if the same antenna is not used), the receiver will only see the radiation that is scattered directly towards the transmitter. This is known as the monostatic measurement case. However, because it is possible to receive a return in other locations, there is sometimes a need to verify the target return (or signature) in these other locations. To do this, a bistatic configuration is required. A bistatic configuration is one in which the transmitting and receiving antennas are not collocated. Instead, some distance separates them. This results in what is known as bistatic RCS, which is usually very different from that of monostatic or back-scattered RCS. To make this measurement, additional

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[1] The term *target* refers to any object being measured at an RCS facility. A target can be an aircraft, ground vehicle, ship, calibration artifact, or a component or subsystem like an antenna or engine nacelle.
[2] *Collimate*: To make parallel; line up; to adjust the line of sight of (as in optical device).

[3] The volume of a compact range where far-field conditions exist is known as the *quiet zone*.

equipment (and usually, additional real estate) is required. Because there are minimal requirements for bistatic measurements (to date) and because of the expense involved, only a few of the available government ranges are capable of these measurements.

Indoor versus Outdoor Ranges

The facilities the government owns and operates can also be divided into either indoor or outdoor ranges. The advantages of indoor ranges include increased physical security, elimination of weather effects, and somewhat greater control over the testing process, like the use of background subtraction to make more accurate measurements. The advantages of outdoor ranges include the ability to measure larger targets, make measurements at lower frequencies and make dynamic measurements of full-size targets.

Static versus Dynamic

Most of the available government ranges make static RCS measurements. That is, the target is placed upon a support structure and measurements are made while the target is in a stationary or quasi-stationary state. To obtain measurements at various aspect angles of a target on a support structure, the target is either slowly rotated about its axis, or the measuring system may be carefully moved about the target. To obtain measurements of a moving target, such as an aircraft flying or a tank traversing the ground, a dynamic range is required. The most important considerations in a dynamic range are being able to accurately determine where the target is at a given moment, while being able to collect enough data to get a valid measurement. Obviously, valid, accurate, dynamic measurements can be more difficult to obtain, as many more support issues come into play in addition to the usual issues involved in making good RCS measurements.

Factors to Consider in Selecting RCS Ranges

When determining which of the available RCS ranges should be used for any given measurement program, many factors come into play. All of these factors fall into one of two general categories: technical or administrative. The decision as to which factors should receive the greatest weight depends mainly on the objectives of the program. In this section, we will list some of the main factors in each category, and leave the assignment of importance to those involved in the specific program.

Technical

When evaluating the technical factors involved in selecting a range, the first thing to consider is the purpose of the measurement. This will determine what frequency coverage will be required. At each frequency of interest, a certain level o f signature will be desired or required. To make a valid measurement at these levels, the background level of the range must be significantly (~20dB) below the desired measurement value.

To determine if the measured values are correct and accurate, the measurements must be calibrated first. An understanding of the calibration process employed by the range will help an evaluator understand the measurement limitations of the range. Key to evaluating the calibration procedures, and in turn, the validity of the range's measurements, is an understanding of the range's uncertainty analysis (error budget). An uncertainty analysis[4] documents the types and quantities of errors that can be expected at a given range under various measurement profiles or configurations. Conducting an uncertainty analysis, and

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[4] The term *uncertainty analysis* is preferred over *error budget*. Beginning in 1997, several ranges initiated a demonstration program aimed at developing a certification process for RCS measurement facilities. A major part of any certification program will include detailed uncertainty analyses.

documenting the results is the first step in creating a measurement process that has a credible audit trail. Without this audit trail, it is difficult to determine the accuracy of the measurements provided as a range's product to the customer. Overall, the presence of a verifiable uncertainty analysis is evidence the range takes the measurement process seriously, and should give the user increased confidence that the range will produce results that will stand up to critical scrutiny by the end user or those in an oversight role.

Another area of evaluation is the target handling capability of the range. Can their range handle a target of the size and weight that the program requires? Additional factors include such items as: whether the target has to be significantly modified before it can be mounted on the available support structure; can the range support full-size targets or must scale models will be used; will available target handling adequately support security requirements.

The way data collection and processing is carried out will have a significant impact on the program's cost as well as success. Some ranges have the capability to make measurements at several frequencies simultaneously, greatly increasing the speed with which measurements can be made. This also has the effect of simplifying the target registration between frequencies. Knowledge of how the data is processed, both during and after collection, is crucial in determining the validity of the data, as well as understanding what the data does and does not mean. Also, different facilities display their data in different formats. This however, is not as critical, as often, the data can be reprocessed for different display formats, as long as the data is properly collected.

Finally, the technical support available at a range can be very significant. For instance, does the range offer the capability to modify the target, if needed'? Is there someone available that can evaluate the results of the measurements as they are made, so problems may be detected while there is a chance they can be corrected?

Administrative

Just as the technical factors involved in making measurements will affect the end result of a measurement program, so too, the administrative factors will determine the success of the program. Among the many factors to consider is the administrative support the range provides. For instance, are transportation, communication and other logistical issues available to support the program office. Are the hours of operation and availability of range time such that the program can be efficiently scheduled to complete the program in a timely fashion.

These days, environmental concerns should not be overlooked. Many localities impose significant limitations on the types of materials that may be released into the environment. For instance the volatile organic compounds that have been associated with certain types of Radar Absorbing Materials (RAM) require special handling and disposal procedures. These procedures may impact schedules if significant target modification involving RAM is required.

Although the issue of security would not seem to be the driver that it once was, in fact it is still one of the major issues that will affect the efficiency and cost of the measurement process. Few factors will affect the measurement process so pervasively, from the number and type of personnel involved, to scheduling and cost. It should go without saying that the lower the security level required, the easier and less expensive the measurement process will be. Having a 24 hour a day measurement window will make scheduling much easier than a requirement for dark-of-the-moon testing, as well as minimizing the effects of adverse weather when measuring outdoors.

Finally, overall cost is a major issue. Because the bulk of the measurements often come toward the end of a program, when funds become tighter, cost is a key factor in being “able to get all the data needed to perform a complete evaluation of the program. The ability of a range to control costs is one of the keys to a successful measurement program. When making a cost comparison between different types of ranges, whether government or contractor, it is important to insure that a valid comparison is made. Because of different types of accounting systems, as well as what is allowed to be incorporated into the various categories such as overhead or direct costs, this is a very difficult exercise.

Additional Information

The information presented in this document is only a high level review of the factors that go into selecting an RCS measurement range. Many issues have not been addressed or only touched upon in a cursory manner. For those that desire/require additional or more detailed technical information, several options are available.

One approach is to take one of the many available short courses concerning RCS. One course that is highly recommended is a 3-1/2 day, government-only short course that is offered approximately once a year. This course covers the fundamentals of RCS analysis, prediction, reduction and measurement. The point of contact for this is Dr. Brian Kent at the Air Force Research Laboratory, Wright-Patterson AFB, OH. He can be reached at (937) 255-0278 or DSN 285-0278. Another appropriate course is the one taught at the Radar Target Scattering Facility (RATSCAT), Holloman AFB, NM. The point of contact is Mr. Jim Eggleston. He can be reached at (505) 679-3365 or DSN 349-3365. This course is more oriented towards RCS measurements than the AFRL course. Both courses will give the attendee a solid background in RCS measurements.

For those interested in obtaining reference material, the books listed below cover in much greater detail the ideas touched on here. Of particular note are the books by Curric (1989) and Knott (1993).

Finally, the points of contact at each of the ranges listed should be able to address most of your questions concerning RCS measurements, especially in regards to their particular ranges.

Further Reading

Curric, N.C., ed. Techniques of Radar Reflectivity Measurements. Artech House, Norwood, MA, 1984.

Curric, N.C., ed. Radar Reflectivity Measurements: Techniques & Applications, Artech House Norwood, MA, 1989.

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Maffett, A.L. Topics for a Statistical Description of Radar Cross Section. Wiley Interscience, John Wiley & sons, New York, NY, 1989.

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Radar Cross Section Measurement Facilities

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